

Development of Sensors for Aerospace Applications

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Abstract

Advances in technology have led to the availability of smaller and more accurate sensors. Computer power to process large amounts of data is no longer the prevailing issue; thus multiple and redundant sensors can be used to obtain more accurate and comprehensive measurements in a space vehicle. The successful integration and commercialization of micro- and nanotechnology for aerospace applications require that a close and interactive relationship be developed between the technology provider and the end user early in the project. Close coordination between the developers and the end users is critical since qualification for flight is time-consuming and expensive. The successful integration of micro- and nanotechnology into space vehicles requires a coordinated effort throughout the design, development, installation, and integration processes.

1.0 Introduction

Some sensors are too big and heavy for deployment in space vehicles, including the Space Shuttle Orbiter. Although there is a need for small and low-power smart sensors (especially if multiple sensors can be integrated into a single substrate to combine different measurements in a single chip), installing additional sensors and instruments is costly and time-consuming. The capability to perform redundant and complementary measurements can result in extended calibration cycles, thus reducing operating and maintenance costs.

Costs associated with wiring and sensor installation are important parameters that are considered when performing cost-benefit analysis. When multiple sensors are involved, intelligence must be embedded at the sensor level to limit the flow of nonessential information and to reduce wiring and signal bandwidth requirements. By using distributed intelligence along with relationship rules, complex processes can be broken down into simpler, smaller ones. Basic knowledge rules incorporated at the sensor can allow decision-making capabilities to be decentralized and located at the site of the physical process being monitored. Furthermore, the health of sensors can be monitored and measurements validated by applying process knowledge rules embedded in the sensors. As a result, data transfer can be minimized by emphasizing transfer of process information versus transfer of raw data.

2.0 Integration of Sensors Into Space Vehicles

For successful integration of new sensors into space vehicles, a close and interactive relationship must be developed early in the project between the technology provider and the end user. The problem and prospective solutions should be clearly identified and well defined to demonstrate that the new technology works satisfactorily in the relevant environment and that it presents no danger or interference to existing systems. The technology provider has to remain involved with the user through installation, acceptance testing, and acclimation of the new technology.

The product developer and end user must jointly perform the following functions:

- Develop a detailed set of requirements: performance, physical, environmental, safety, reliability, and maintainability.
- Establish the qualification process to certify the product.
- Define the documentation requirements for the qualification process.
- Establish a quality control process to monitor the design, fabrication, testing, and integration of the product into the vehicle or the ground support system.

It is important that the performance requirements established by the user be well defined before any potential solution to a problem is considered viable. Among the performance requirements that have to be specified are:

- Sensor characteristics: accuracy, sensitivity, selectivity, dynamic range, stability, and noise behavior.
- Physical characteristics: size, weight, volume, and mechanical and electrical interfaces.
- Environmental constraints determined by mission to be performed: vibration, shock, corrosion, radiation, thermal management, etc.
- Safety and reliability: as established by the end user, including the assessment of materials compatibility and intrinsically safe designs for hazardous environments.

3.0 Work in Progress Involving the Implementation of Micro- and Nanosensors at the Kennedy Space Center (KSC)

ASRC Aerospace is involved in various activities related to the development of micro- and nanosensors for space and ground support applications at KSC in Florida.

3.1 E-nose

An e-nose consists of an array of nonspecific vapor sensors. In general, the sensor array is designed so each individual sensor responds to a broad range of chemicals but with a unique sensitivity relative to the other sensors. Chemical identification is achieved by comparing the sensor response pattern of an unknown vapor to previously established patterns of known vapors. In addition to their sensitivity and

flexibility, e-noses are small, lightweight, rugged, and inexpensive, and they require relatively low power, thus making them ideal for enhancing the reliability and safety of any enclosed environment. The e-nose technology is being advanced for direct applications to the specific needs at KSC, including the identification and quantification of the composition of mixed vapors.

3.2 Hydrogen Detectors

Hydrogen sensors suitable for space applications and based on coated carbon nanotubes are currently being developed and evaluated by ASRC Aerospace at KSC. All the required environmental testing and materials compatibility analyses are currently being conducted. Further, in conjunction with other NASA Centers, technical expertise is being provided for the transition of microelectromechanical systems (MEMS)-based sensors into units suitable for space applications.

3.3 Reconfigurable Circuits

Reconfigurable circuits can result in self-healing capabilities for a data acquisition system. The development of the Advanced Data Acquisition System (ADAS) has provided increased benefits to satisfy the aerospace industry need to reduce operations cost, accelerate processing time, and provide reliable hardware at a reasonable cost. An innovative approach to data acquisition systems resulted in the design of the ADAS. Among the benefits provided by ADAS are:

- Electronic health self-check
- Device/system self-calibration
- Electronics and function self-repair
- Failure detection and prediction
- Power management for reduced power consumption

The incorporation of Field-Programmable Gate Arrays (FPGAs) and Programmable Analog Integrated Circuits (PAICs) has resulted in a highly flexible circuit architecture capable of reconfiguring itself upon internal or external control. A detailed evaluation of the mean time between failures (MTBF) determined the components for which "*spare parts*" had to be made available. The self-calibration activities of ADAS utilize precise signal references for in-process determination of signal processing accuracies and appropriate signal/gain adjustments. This information also provides for self-health assessment and inherent system health trending. Advanced embedded software and digital switching components and techniques make self-calibration and self-repair possible without interruption of ongoing signal processing.

3.4 Acoustic Sensors

Determining the extent and location of possible structural damage is important in many engineering systems, ranging from advanced aerospace structures such as the International Space Station and the Space Shuttle to future reusable launch vehicles for the Moon and Mars. In the past, the primary inspection method for these structures has been visual, with occasional employment of conventional nondestructive evaluation techniques.

Evaluating acoustic emissions provides a nondestructive test method for determining or monitoring material or structural integrity based on the release of energy detectable by analysis of the emission frequency and amplitude. By instrumenting a

critical structure with acoustic emissions, any impact or structural failure can be identified and located in real time. Work is in progress on sensors and signal processing algorithms to determine of the nature of structural damage from impact.

4.0 Summary

The successful integration of micro- and nanotechnology into space vehicles requires a coordinated effort throughout the design, development, installation, and integration processes. The selection of materials for sensors and associated instrumentation is critical because certain materials can cause hazards in the space environment that are not apparent in the ground environment. Materials should be selected early, and their use approved by the user.

It is important to involve the safety community early in the design, even during the conceptual design phase. Certification and safety problems that are often found late in the design cycle can be avoided easily and less expensively if they are addressed early in the process.

Flight and ground operations personnel should also contribute to the design process since they are the people who will be installing sensors and instrumentation, as well as operating the systems. They understand the vehicle and support systems that will be required to support the installation and operation of new systems. They have seen many pitfalls and can help the developer avoid them.

Scientists and engineers strive to build scientifically perfect systems, regardless of the time required. Flow managers must ensure that all experiments and systems are integrated so the overall mission launches on time. Compromise is necessary to develop the best systems possible for an operational environment.

ASRC Aerospace is continuing to design and develop micro- and nanosensors and instrumentation for space applications, not only in the Space Shuttle Orbiter but, more important, in the next-generation vehicle scheduled to replace the Orbiter by 2010.